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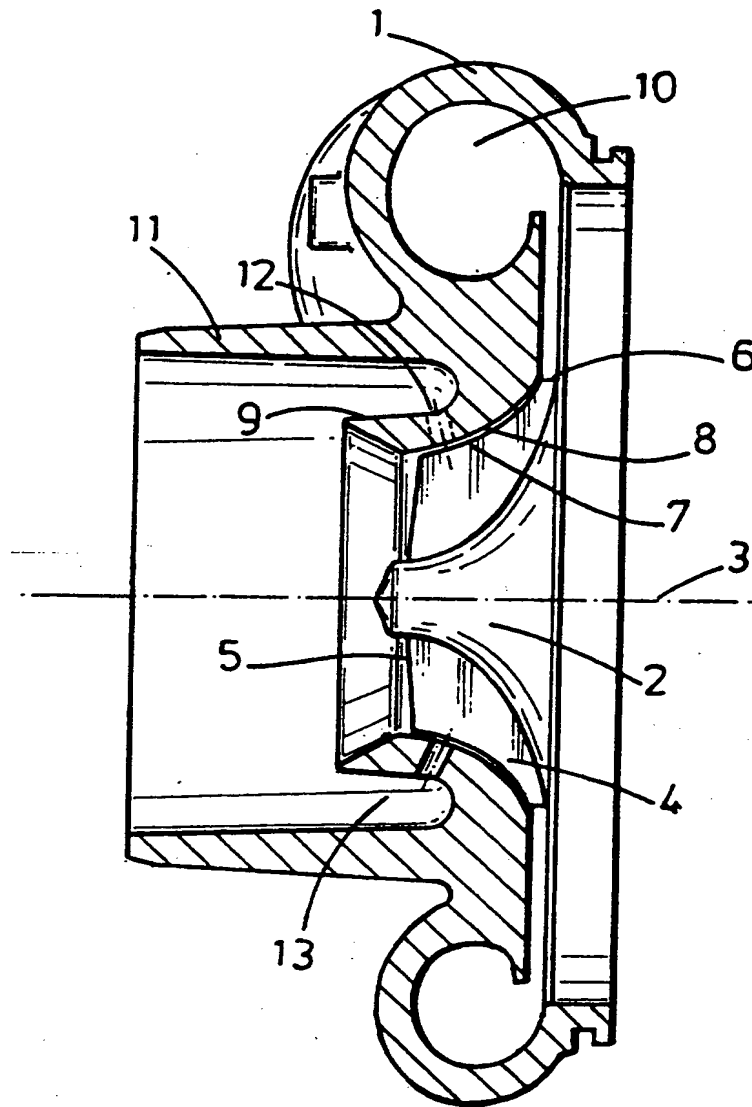


FIG. 1

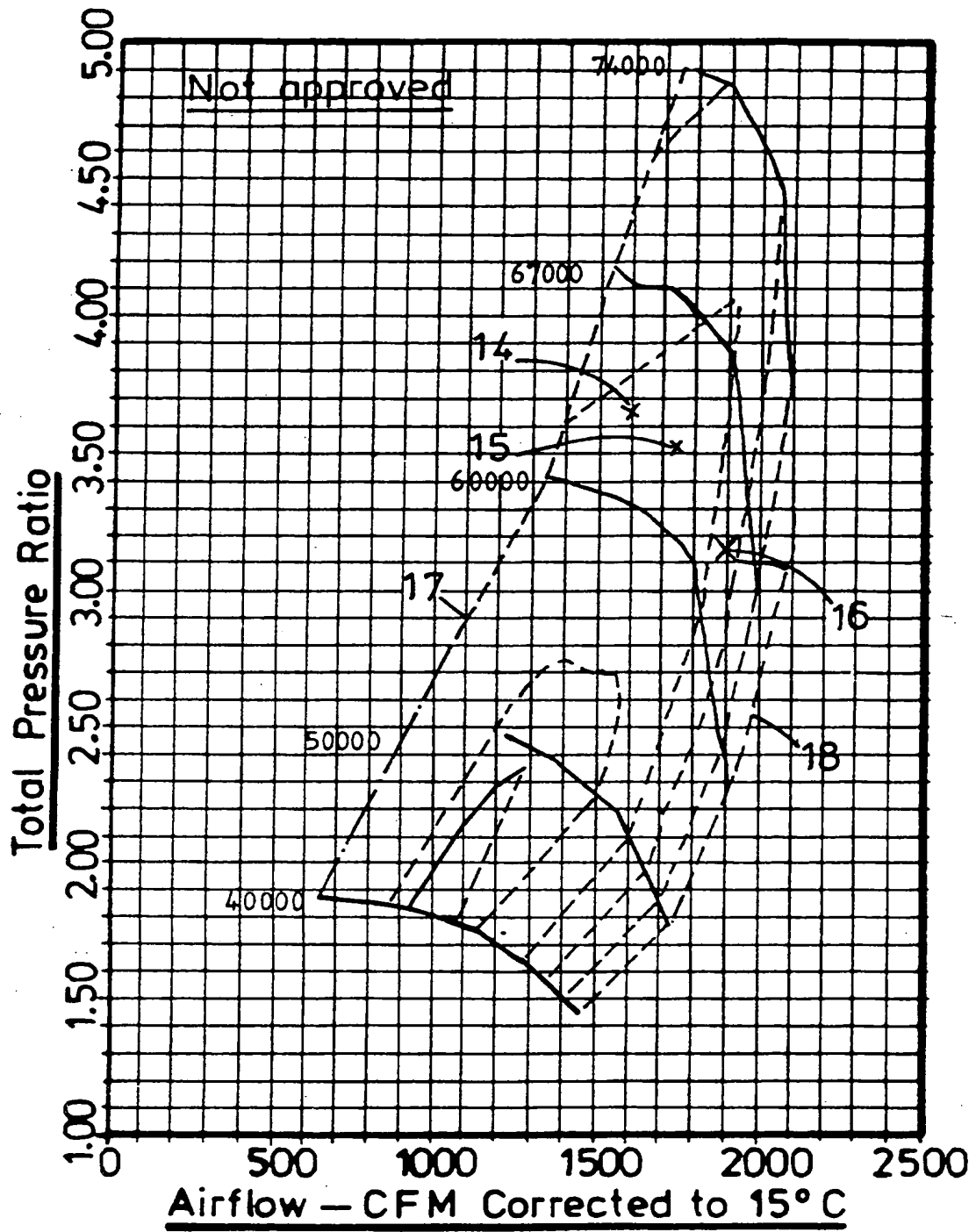


FIG. 2

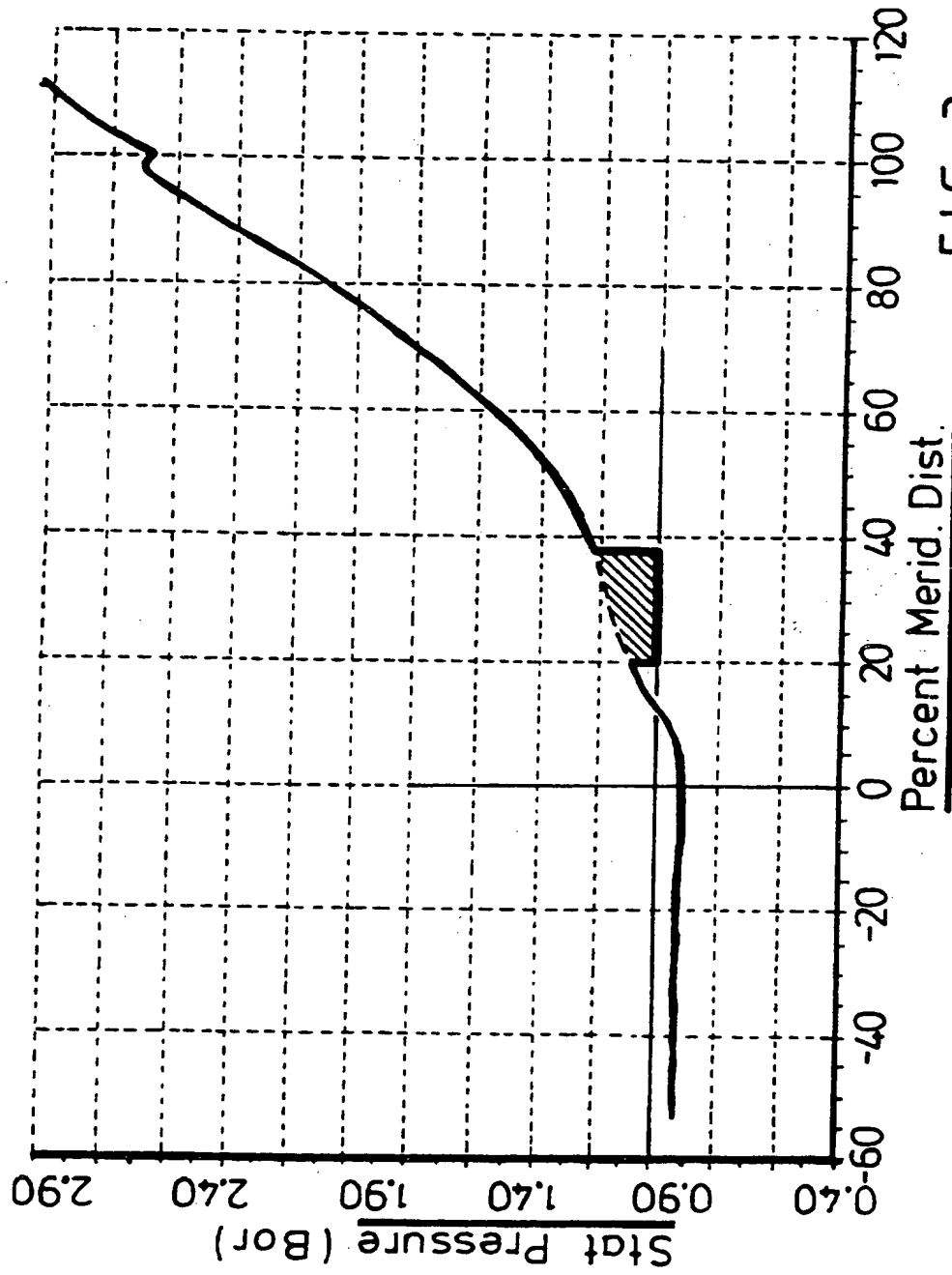


FIG. 3

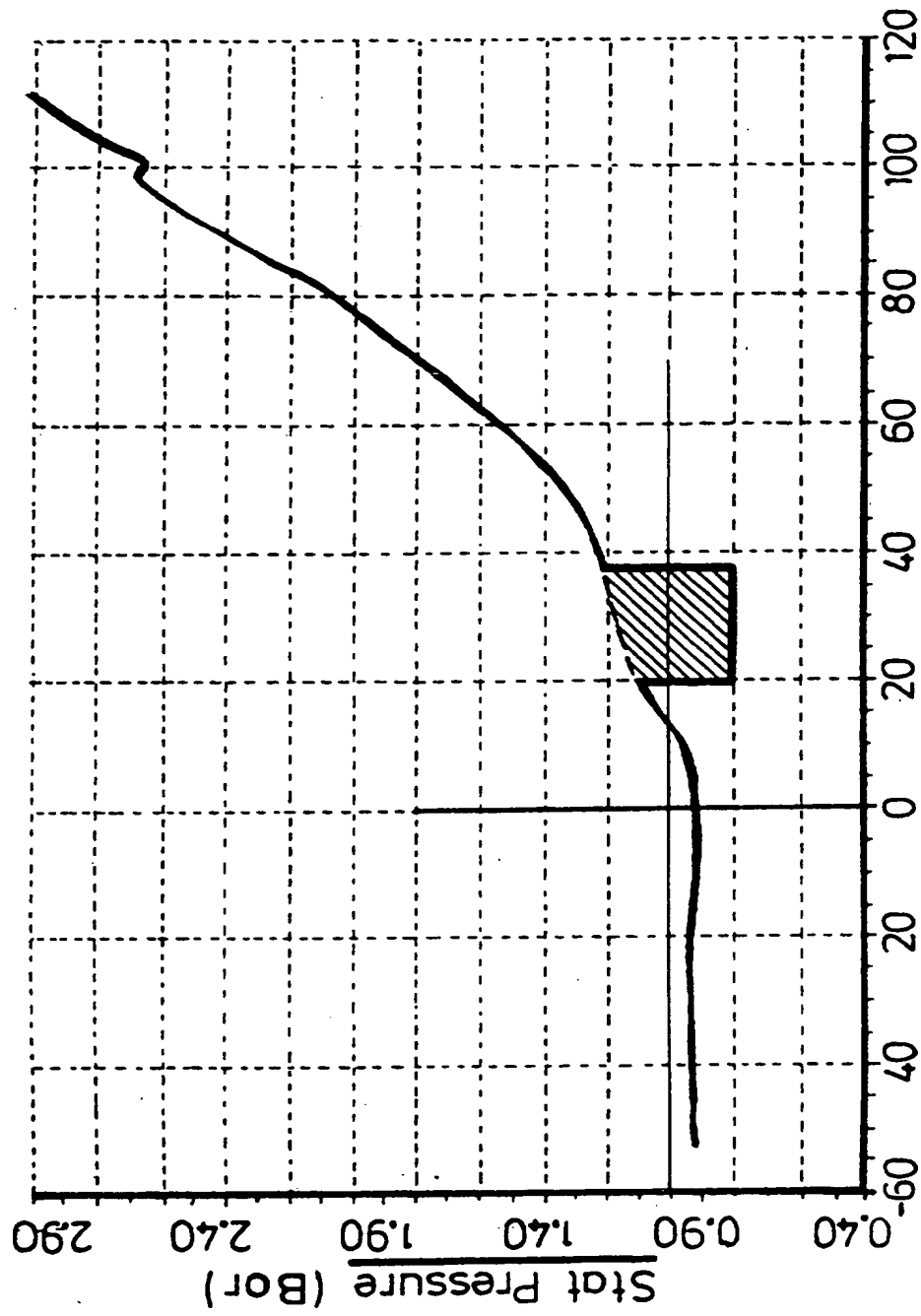


FIG. 4

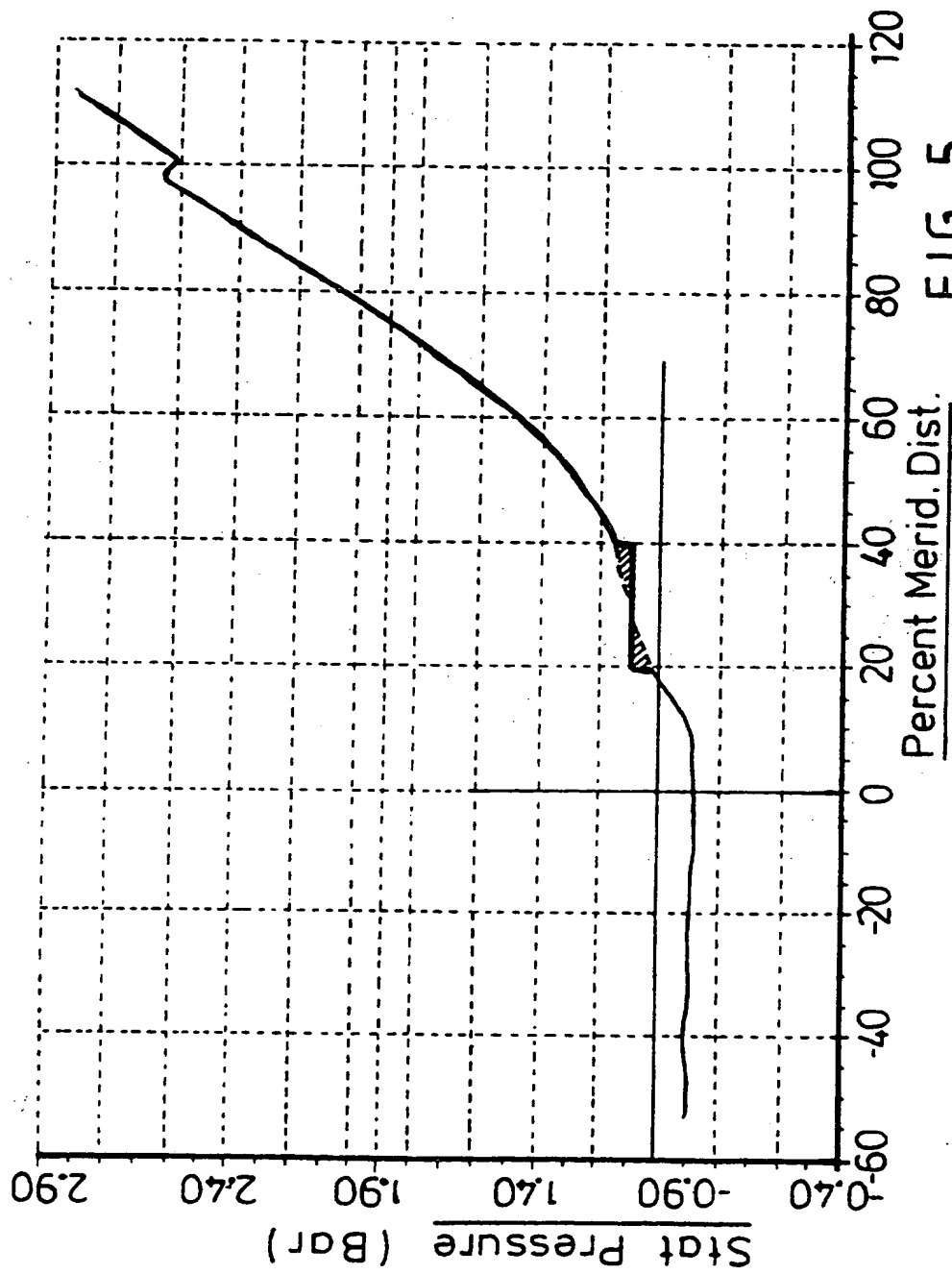
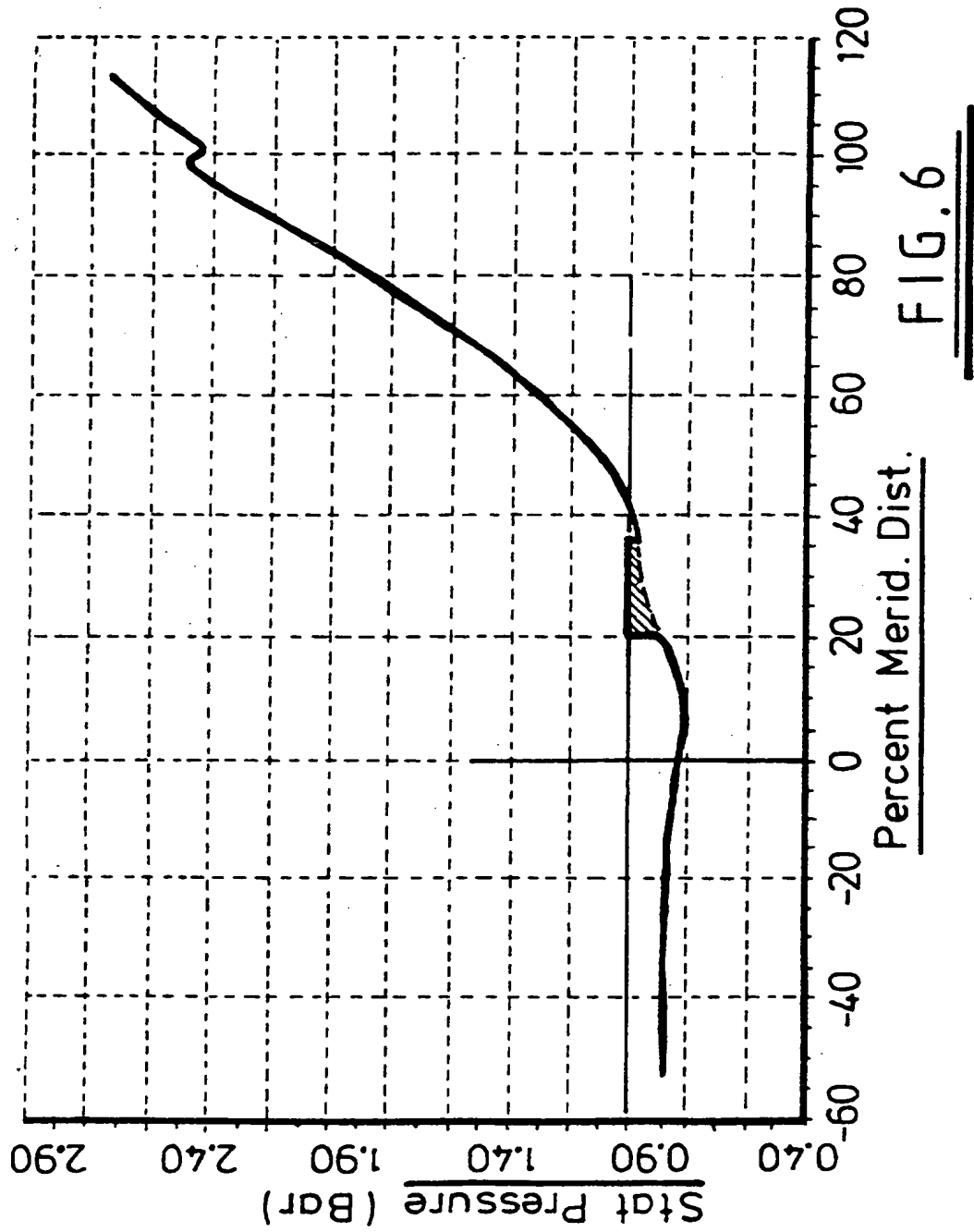
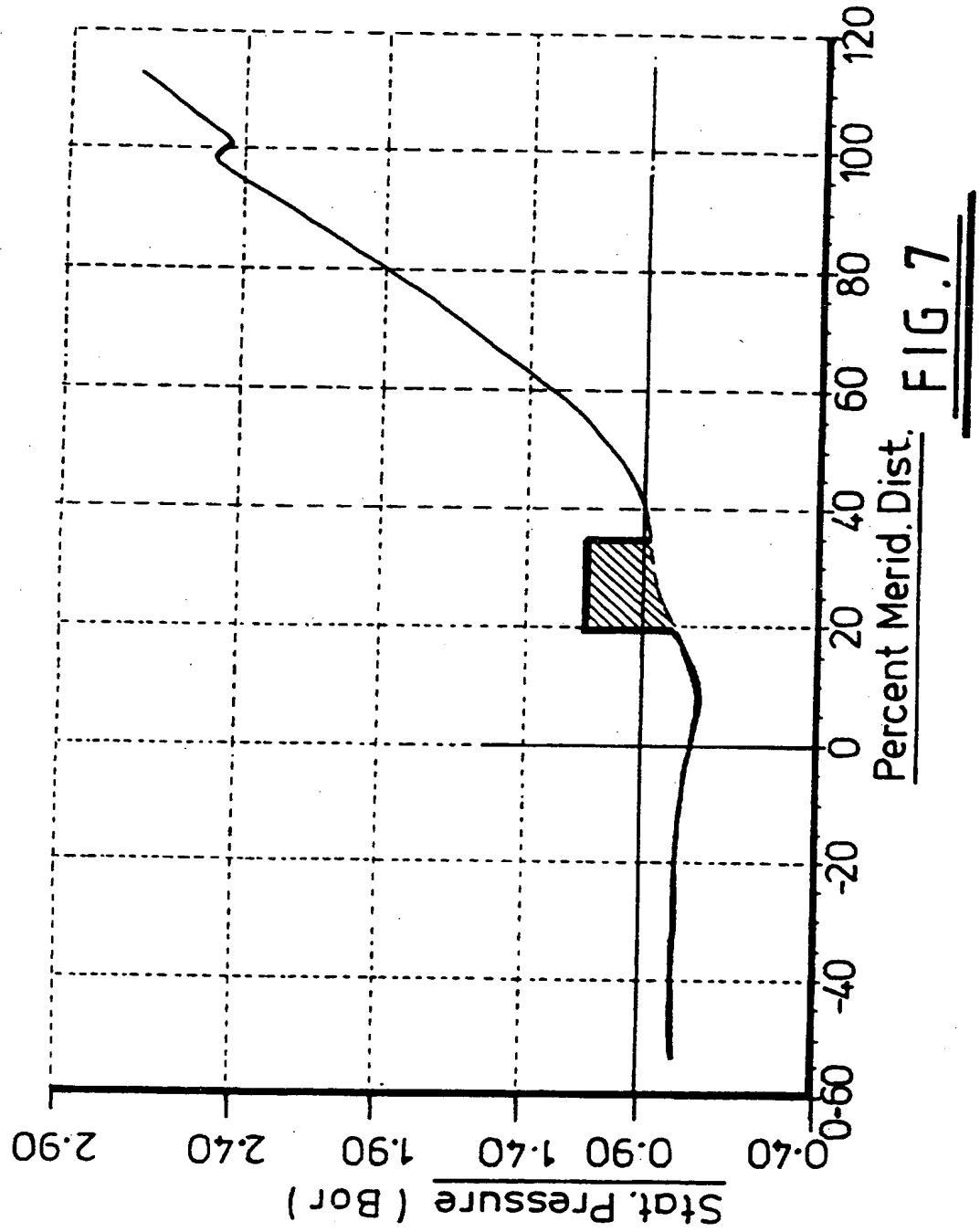


FIG. 5





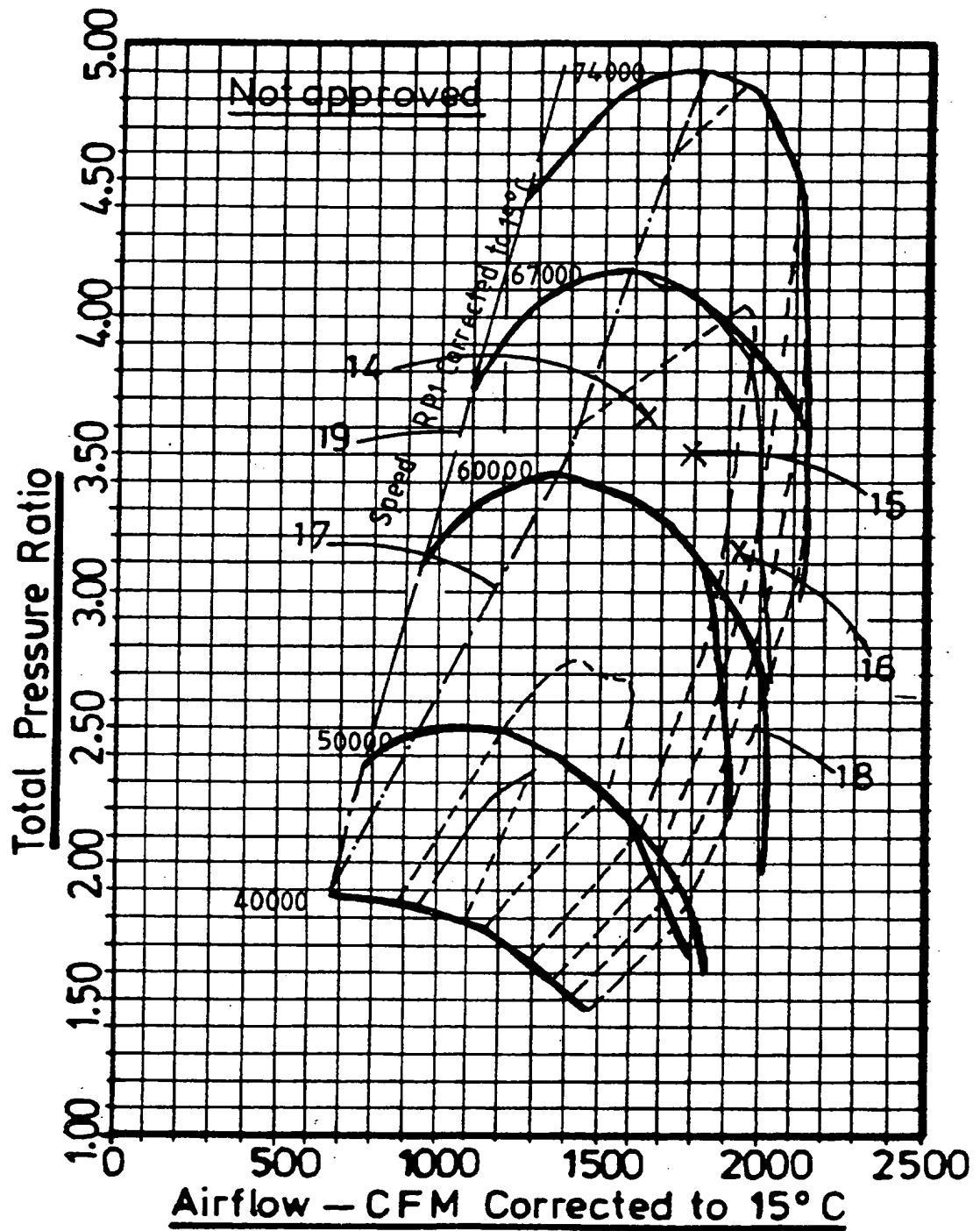


FIG. 8

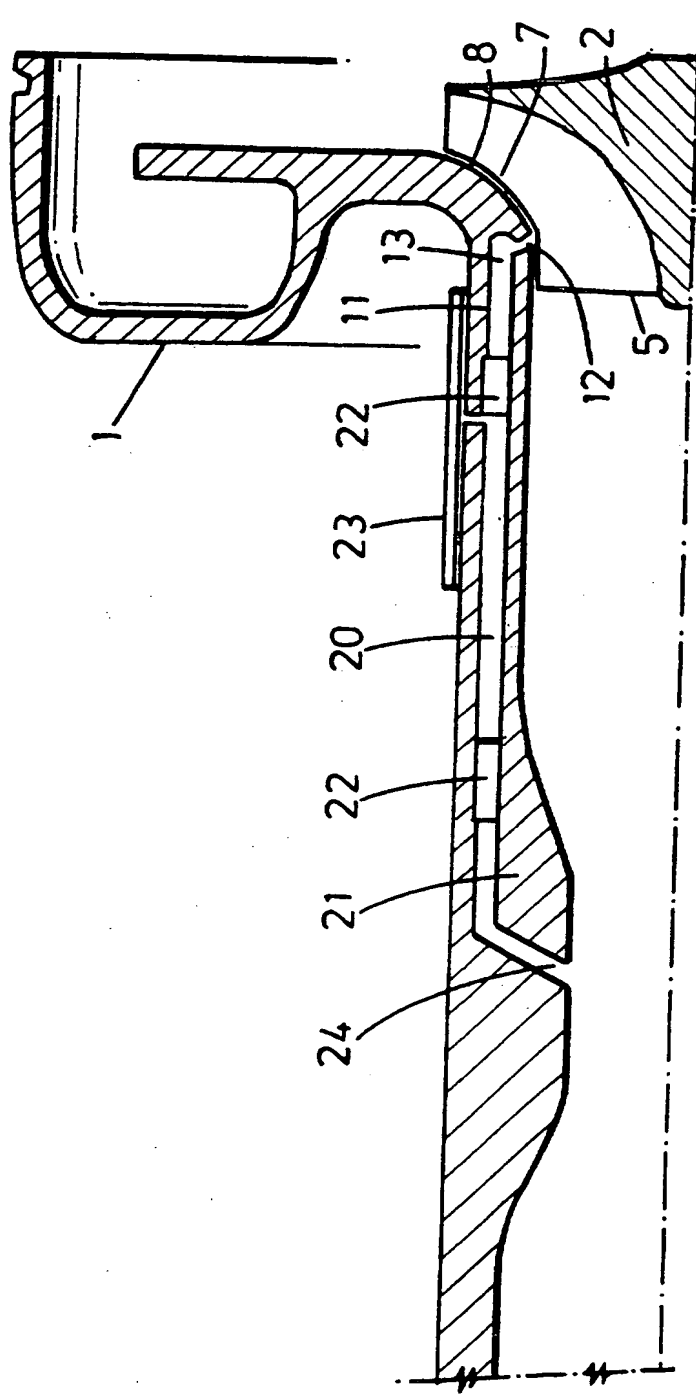


FIG. 9

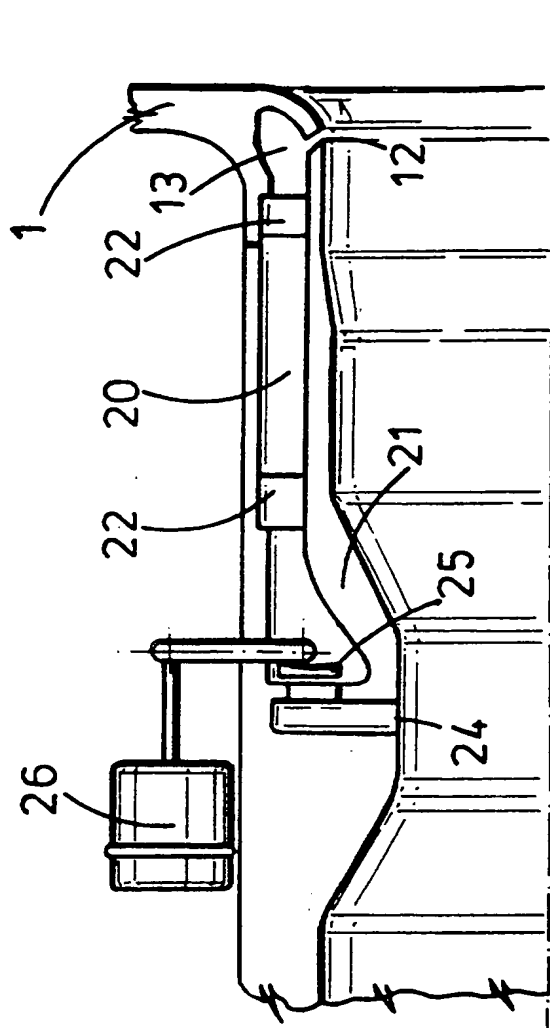
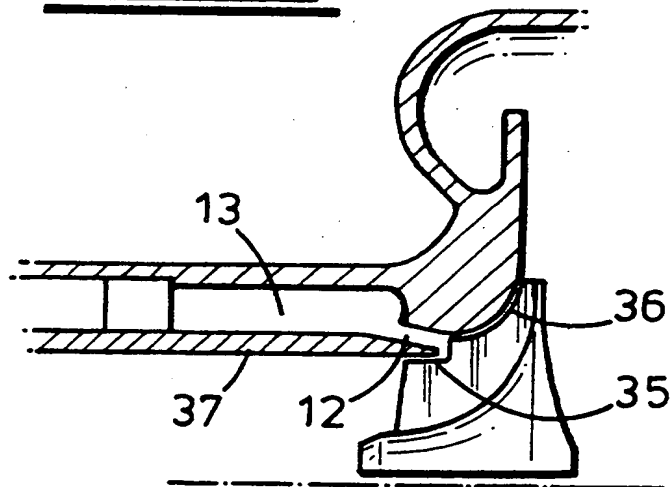
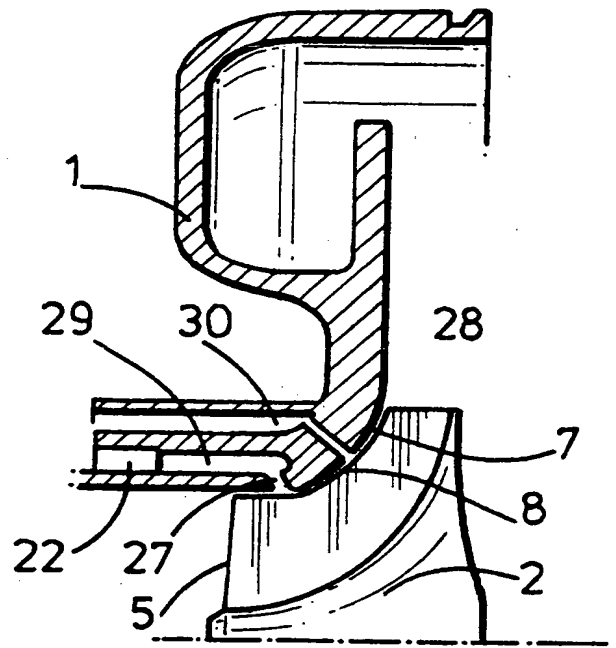


FIG. 10



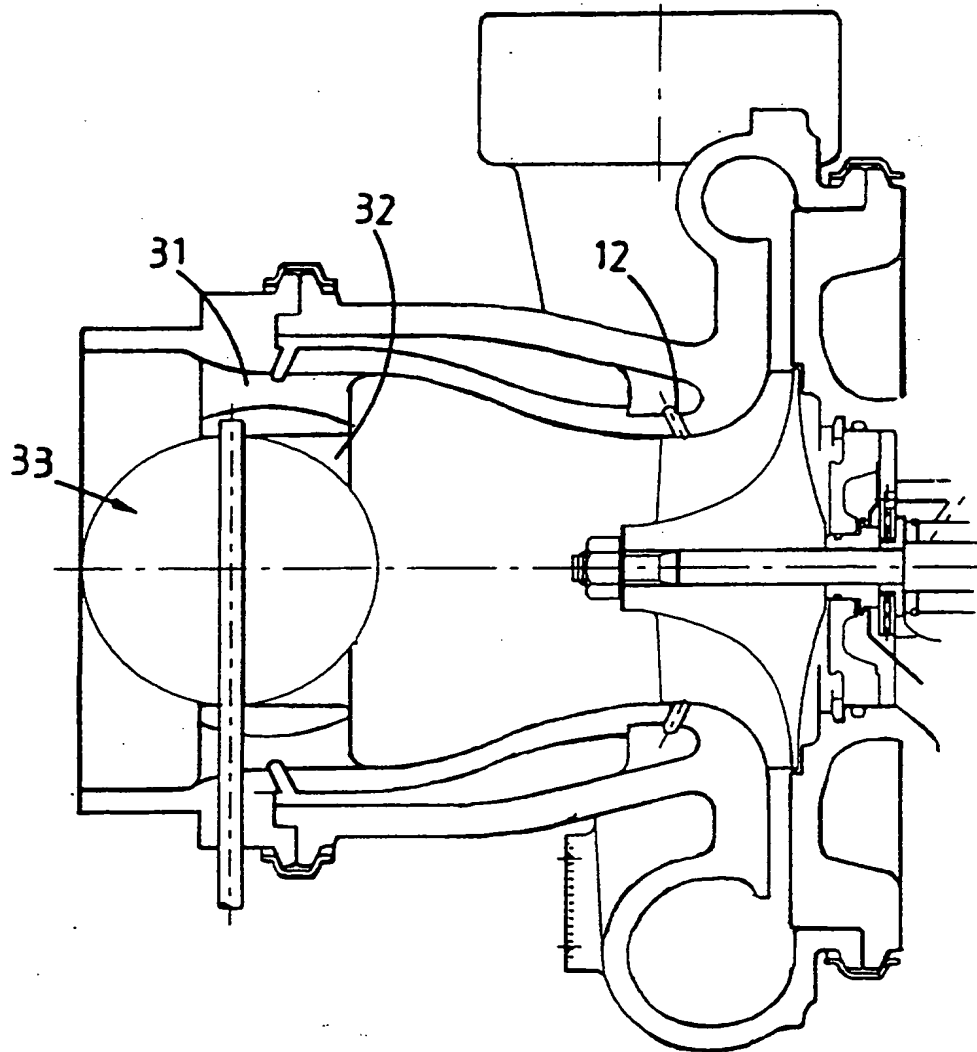
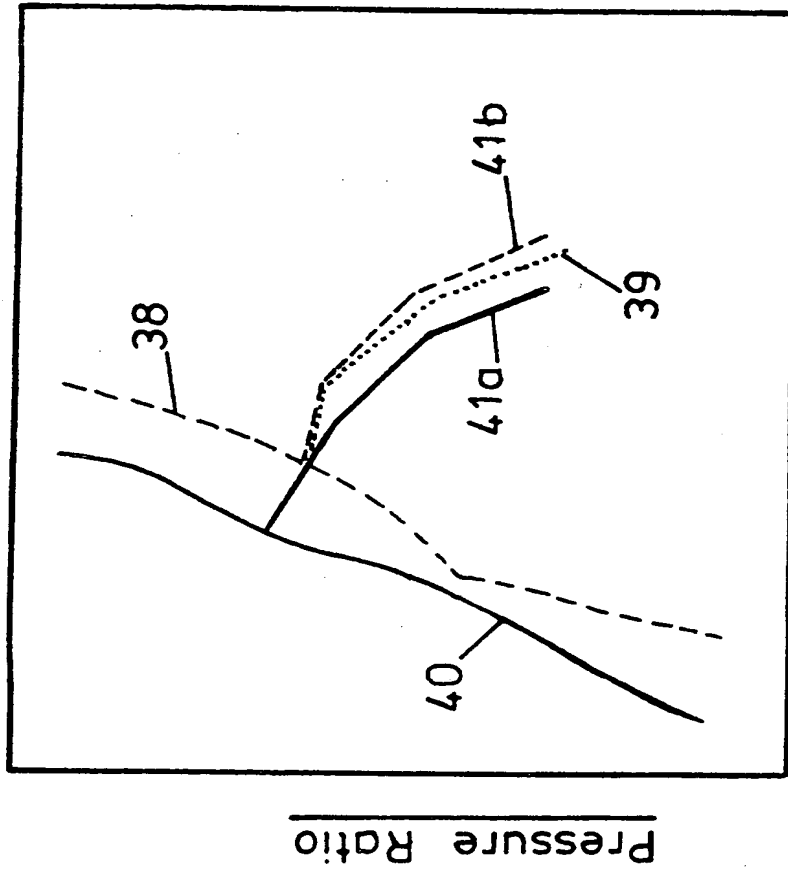


FIG. 12



Flow Parameter

FIG. 14

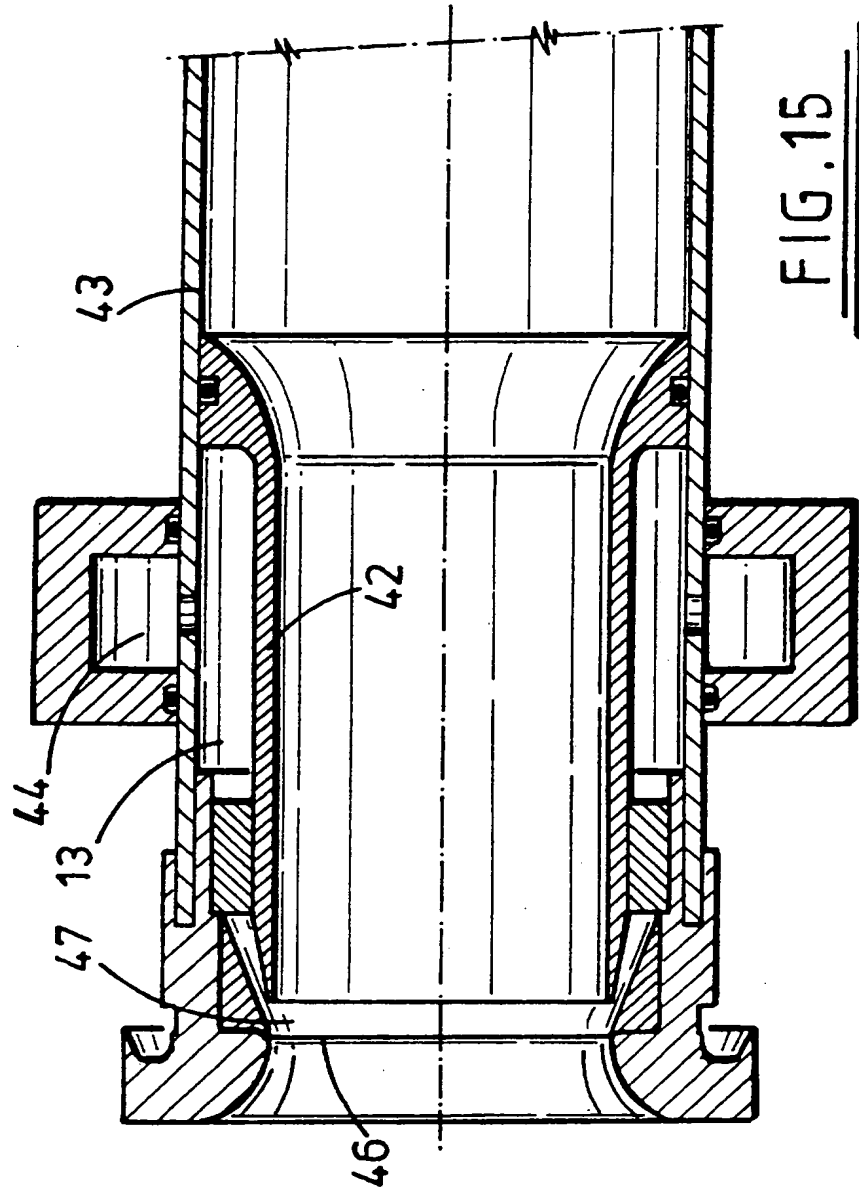


FIG. 15

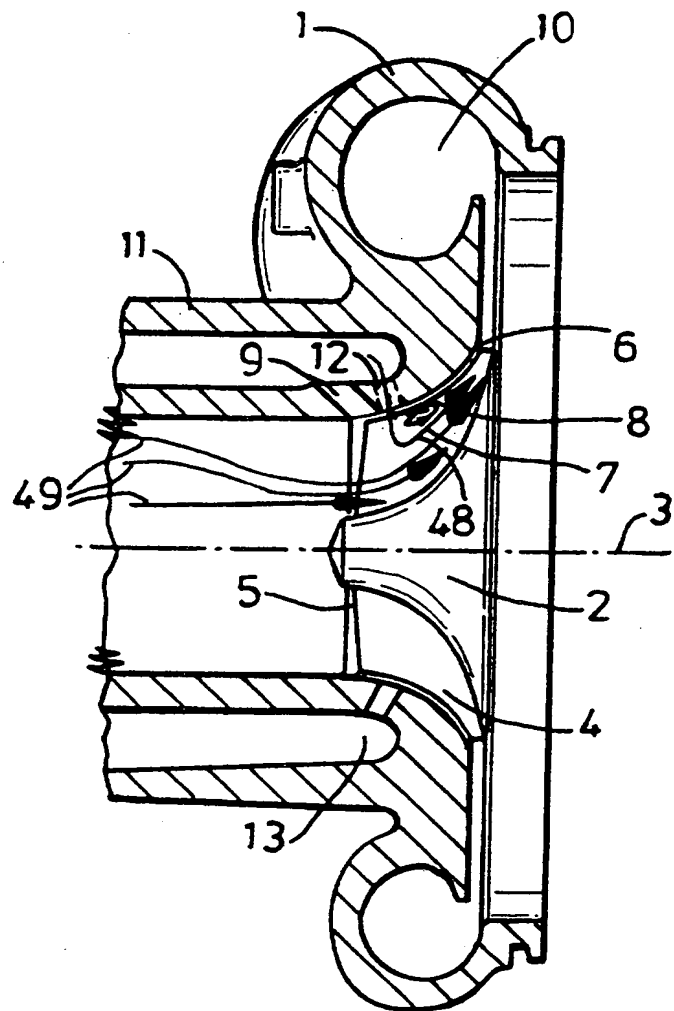
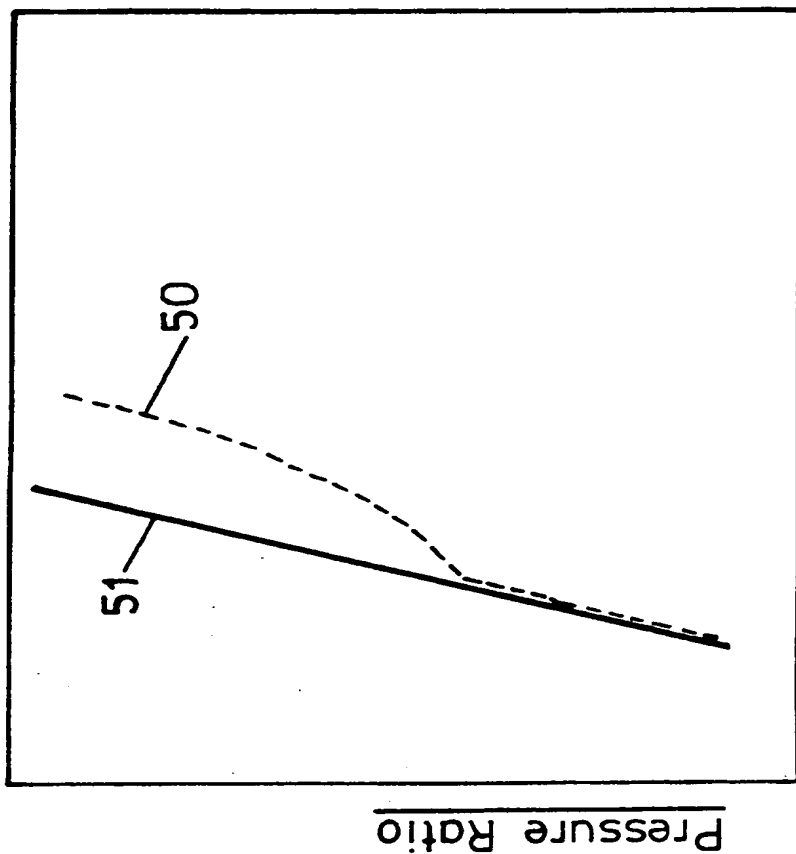


FIG. 16



Gas Flow

FIG. 17

COMPRESSOR

The present invention relates to a compressor, and in particular to a compressor having an enhanced map width.

Map width enhanced compressors are known which comprise a stationary housing defining an inlet and an outlet, and an impeller wheel mounted for rotation within a chamber defined by the housing between the inlet and outlet, the wheel including a series of blades each of which has an upstream edge adjacent the downstream end of the inlet and a radially outer edge which is in close proximity to and sweeps across an inner surface of the housing chamber. A passageway as defined by the housing between a first opening in a portion of the inlet spaced from the upstream edges of the blades and a second opening in the inner surface of the housing chamber which is swept by the radially outer edges of the blades.

The passageway increases the amount of gas reaching the impeller wheel during high flow and high rpm operation and recirculates gas to the compressor inlet during low flow operation. Such an arrangement results in improved stability at all speeds and a shift in the characteristics of the compressor. This shift can be represented as a widening of a standard "map" which plots the total pressure ratio of the compressor against corrected air flow. Details of a conventional map width enhanced compressor are described in European Patent Specification No. 0229519.

Although conventional map width enhanced compressors exhibit good stability, it would be advantageous to be able to enhance the performance of such compressors in low and high flow conditions. It is an object of the present invention to provide such an improved compressor.

According to the present invention, there is provided a compressor comprising a stationary housing defining an inlet and an outlet, and an impeller wheel mounted for rotation within a chamber defined by the housing between the inlet and outlet, the wheel including a plurality of blades each of which sweeps across an inner surface of the housing chamber, and the housing defining at least one passageway communicating with at least one opening located in the surface of the housing chamber adjacent the wheel, wherein pressure control means are provided to control the pressure within the passageway. The pressure may be controlled as a function of the flow rate through the compressor.

The invention improves the compressor characteristics by modifying the pressure which would normally be achieved in the passageway defined in a conventional map width enhanced compressor. The change in pressure could be produced by any convenient means, for example by providing a venturi in the inlet, the passageway communicating with the throat of the venturi. Alternatively, in contrast to a conventional map width enhanced compressor, the passageway may be connected to an independent pressure source rather than to a part of the inlet upstream of the compressor wheel.

In one possible arrangement the pressure control means maintains a pressure within the passageway less than that within the inlet at least when the flow rate is low relative to a predetermined flow rate. The passageway may extend between the opening adjacent the wheel and a further opening located in the throat of a venturi within the inlet. The passageway may be blocked when the flow rate is high relative to a predetermined flow rate. A further passageway may be arranged to bypass the venturi, means being provided to obstruct the bypass passageway when the flow rate is low relative to a predetermined flow rate.

The passageway adjacent the opening may be arranged such that gas issuing from the opening is directed in a direction with a substantial axial component relative to the axis of rotation of the wheel, and the pressure control means may maintain a pressure within the passageway which is higher than that within the inlet at least when the flow rate is high relative to a predetermined threshold. The inlet may be defined by a tubular cone received within a tubular support, the passageway being defined between the cone and the housing, the opening being defined between one end of the cone and the housing, and the passageway communicating with the pressure control means through at least one opening in the tubular support.

Alternatively, each blade may comprise an upstream edge adjacent the inlet, a first radially outer edge which is in close proximity to and sweeps across the inner surface of the housing, a second radially outer edge which is in close

proximity to and sweeps across a surface defined by the inlet, and an intermediate edge extending between the first and second radially outer edges, the opening facing the intermediate edges of the vanes.

In another arrangement in accordance with the invention, the passageway adjacent the opening is arranged such that gas issuing from the opening is directed in a direction with a substantial radial component relative to the axis of rotation of the wheel, and the pressure control means maintains a pressure within the passageway which is higher than that within the inlet only when the flow rate is low relative to a predetermined threshold.

The predetermined thresholds referred to above may be selected to suit each particular application and the pressure within the passageway may be modulated in a manner appropriate to a particular application. Thus for example in a particular arrangement the pressure within the passageway may be varied continuously with flow rate or a parameter related to flow rate, or may change in a plurality of steps over a range of flow rates.

Embodiments of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a cross-section through part of a conventional map width enhanced compressor;

Figure 2 is a graph of the total pressure ratio against air flow corrected to 15⁰C for the compressor of Figure 1;

Figure 3 is a graph representing static pressure along the surface of the compressor housing swept by the compressor wheel blades against the meridional distance along the axis of the wheel, showing the effect of a slot in the housing wall of the compressor of Figure 1;

Figure 4 is a graph similar to that of Figure 3 showing the effect of reducing the pressure within the slot in accordance with the present invention;

Figure 5 is a graph similar to that of Figure 3 but showing the pressure for conditions in which the compressor is operating at maximum efficiency and there is no flow through the compressor housing slot;

Figure 6 is a view similar to that of Figure 3 but showing the pressure at a flow rate corresponding to the compressor operating near choke;

Figure 7 is a view similar to that of Figure 6 but showing the effect of increasing the pressure within the slot of the housing of Figure 1;

Figure 8 is a map of total pressure ratio against airflow corresponding to that of Figure 2 but showing the improvement which results from applying a partial vacuum to the slot during low flow conditions;

Figure 9 illustrates a first structure in accordance with the present invention for applying a partial vacuum in the slot;

Figure 10 shows a second embodiment of the invention for applying a partial vacuum to the slot except during high flow conditions;

Figure 11 illustrates a multislot structure in accordance with the invention;

Figure 12 schematically represents a further embodiment of the present invention in which a venturi is provided with a bypass;

Figure 13 schematically represents a further embodiment of the invention in which slots direct a flow axially relative to the compressor wheel;

Figure 14 illustrates the response achieved with the arrangements illustrated in Figure 13;

Figure 15 schematically represents a further embodiment of the invention in which the slots direct flow axially;

Figure 16 illustrates an alternative embodiment of the present invention in which radial flow from the slots is used to control effective inlet size; and

Figure 17 represents the performance achieved with an arrangement as illustrated in Figure 16.

Referring to Figure 1, the illustrated compressor comprises a housing 1 within which an impeller wheel 2 is mounted for rotation about an axis 3. The wheel 2 supports an array of blades 4 each of which has an upstream edge 5, a downstream edge 6, and a radially outer edge 7 which is in close proximity to and sweeps across an inner surface 8 of the housing. The housing includes a tubular section 9 immediately upstream of the impeller wheel which forms a short tubular inlet to the impeller wheel. The housing also defines an outlet which is connected to a passageway 10 to which the impeller wheel delivers compressed air.

The housing defines a tubular intake 11 which extends around and projects from the end of the tubular inlet 9. An annular slot 12 is formed through the housing wall so as to open in the face 8 which is swept by the radially outer edges 7 of the impeller blades. The slot 12 communicates with an annular space 13 defined between the housing sections 9 and 11 and that annular space together with the slot 12 defines a passageway which extends from the upstream end of the inlet 9 to the surface 8.

In operation, the wheel 2 is rotated for example by a turbine (not shown) attached to a common shaft with the wheel 2. This causes air to be drawn into the wheel 2 through intake 11 and inlet 9. The air is compressed and then fed to its ultimate destination via the passageway 10.

The pressure in the annular space 13 defined between the housing sections 9 and 11 is normally lower than atmospheric pressure. During high flow and high rpm operation of the compressor, the pressure in the slot 12 immediately adjacent the impeller wheel blades 4 is less than the pressure in the annular space between the housing portions 9 and 11, and as a result air flows through the slot 12 towards the impeller wheel. If the flow through or the rpm of the impeller wheel 2 then falls, so the amount of air drawn into the wheel 2 through the slot 12 decreases until equilibrium is reached. A further decrease in impeller wheel flow results in the pressure within the slot 12 immediately adjacent the wheel blades 4 being greater than the pressure in the annular space between the housing sections 9 and 11 and therefore air flows through the slot 12

away from the impeller 2. This air flow is recirculated to the compressor inlet. The flow through the slot 12 thus improves the stability of the compressor at all speeds as compared with a compressor in which the slot 12 is not present.

Figure 2 shows a typical compressor characteristic using the conventional map width enhanced structure as illustrated in Figure 1. Three points 14, 15 and 16 within this characteristic have been selected for analysis, the graphs shown in Figures 3 and 4 corresponding to point 14, the graph shown in Figure 5 corresponding to point 15, and the graphs shown in Figures 6 and 7 corresponding to point 16. Point 14 represents conditions in which the compressor is operated close to surge, point 15 represents operation at maximum efficiency, and point 16 represents operation close to choke flow. It would be highly desirable if the surge limit represented by line 17 could be moved to the left so as to increase the circulation flow and thereby stabilise the compressor at lower net flows, and it would also be advantageous to be able to move the choke limit represented by line 18 to the right.

Figure 3 shows the pressure distribution within the compressor assuming that the operating conditions are such that the pressure within the slot 12 of Figure 1 is substantially equal to atmospheric. The shaded area represents the effect of the presence of the slot 12, the broken line representing the pressure which would apply in the absence of the slot 12. Figure 4 represents the same operating conditions as Figure 3 except for the fact that the pressure within the slot 12 has been reduced from 1 bar to 0.8 bars. It will be noted that the shaded

area has increased considerably, representing a significantly increased flow of air into the impeller wheel 2 from the tubular section 9 and from the wheel into the slot 12 of Figure 1. Figure 5 shows the pressure distribution at the maximum efficiency operating point 15 of Figure 2. There is minimal net flow into or away from the impeller wheel. Figure 6 shows the pressure distribution assuming operation at point 16 of Figure 2, the shaded area representing the flow of air into the impeller wheel. Figure 7 shows the effect of increasing the pressure in the slot 12 so as to increase the flow into the impeller wheel.

The improved flow characteristics represented in Figures 4 and 7 can be achieved in accordance with the invention in any convenient manner, various possibilities being described below with reference to Figures 9 to 17. The effect of applying the pressure as indicated in Figure 4 is illustrated in Figure 8 in which it will be noted that as compared with the surge limit line 17 as shown in Figures 2 and 8 which is relatively close to operational point 14 a new considerably displaced surge limit has been established as represented by line 19.

Referring to Figure 9, a first embodiment of the present invention is illustrated. The same reference numerals are used in Figures 9 to 17 for equivalent components shown in Figure 1. In Figure 9, it will be noted that the slot 12 opens into annular spaces 13 and 20 defined on their radially outer sides by the intake 11 and a tubular intake extension and on their radially inner sides by a tubular member 21. The tubular member 21 is supported on ribs 22 and the intake 11 and intake extension are interconnected by a hose 23. The spaces

13 and 20 define a passageway between the slot 12 and an opening 24 located in the throat of a venturi defined within the intake. Thus air flow towards the impeller wheel 2 results in a pressure differential between the opening 24 and the region immediately upstream of the upstream edges 5 of the impeller wheel. This differential pressure tends to increase the flow of air from the slot 12 towards the opening 24. This is clearly advantageous at low net flow rates as represented by Figure 4. It would be a disadvantage however at high flow rates.

In a second embodiment of the invention illustrated in Figure 10, a flap valve 25 controlled by an actuator 26 is arranged to selectively obstruct the passageway between the slot 12 and the opening 24. Thus at relatively low flow rates the flap valve 5 is open to establish a pressure differential as indicated in Figure 4. The flow rate is sensed and used to control the actuator 26 such that the flap valve 25 closes when the condition represented by point 15 in Figure 8 is reached, that condition corresponding to Figure 5. Thereafter, assuming conditions change to those represented by point 16 in Figure 8 the pressure distributions correspond to that shown in Figure 6 except for the fact that there would be no net flow through the slot 12.

On compressors of relatively large physical size more than one slot could be used. Such an arrangement is illustrated in Figure 11. In Figure 11 two slots 27, 28 are provided in the surface 8 which is swept out by the radially outer edges 7 of the impeller wheel 2. The slot 27 communicates with a passage 29 and the slot 28 communicates with a passage 30. These two passages may in turn

communicate with a common opening located adjacent a venturi upstream of the impeller wheel or alternatively may communicate with separate openings located at different positions in a venturi throat. Pressures would be supplied to the openings that would be less than the pressure immediately upstream of the impeller wheel. In such an arrangement the pressure in passageway 29 would typically be less than ambient while the pressure in passageway 30 would be higher than in passageway 29 but less than in the opening in wall 8 defined by the slot 28. Other options would be to arrange for the pressure in passageways 29 and 30 to be greater than that within the blade outer edge (edge 7 in Figure 1).

The passageway 30 could receive gas from a different source as compared with the passageway 29. For example the passageway 30 could be connected to receive exhaust gas from the turbine inlet of a turbocharger, the exhaust gas being delivered to passageway 30 through a cooler.

Figure 12 illustrates an alternative embodiment of the invention for use in applications where it is desired to achieve a large displacement of the surge line in low flow conditions without unduly restricting the gas flow in high flow conditions. As shown in Figure 12, a venturi is defined by an annular passage 31 which extends around a circular section passage 32 within which a butterfly valve 33 is positioned. In high flow conditions the butterfly valve is open as shown so that the passage 31 bypasses the venturi and the pressure in the slots 12 is as a result close to atmospheric. In contrast, in low flow conditions, the butterfly valve is closed to direct air through the venturi and thereby apply a

reduced pressure to the slots 12. Thus in the arrangement of Figure 12 the venturi differential can be matched to the required position of the surge line without unduly restricting flow in higher flow conditions.

Figure 7 suggests that, in high flow rate conditions, increasing the pressure in the slot 12 of a conventional arrangement such as that shown in Figure 1 would be expected to result in increased flow that should manifest itself in a displacement towards the right of the choke flow limit 18 of Figure 2. This would be highly desirable. However, tests have shown that little benefit can be gained if the slot 12 is directed towards the wheel axis. It has been discovered however that if the slot is arranged to extend in a direction with a substantial axial component, for example in a direction inclined by from 10 to 15 degrees to the axis, the choke flow line can be displaced in a significant manner.

Figure 13 illustrates an embodiment of the invention with axially-directed slots 12 communicating with an annular passageway 13. The slots 12 face edges 34 of the blades which extend radially between radially outer edges 35 and 36 such that each blade has a step shape. The edge 35 sweeps across an inner surface of a tubular sleeve 37 which defines one side of the passageway 13. With the arrangement of Figure 13, choke capacity may be increased when the passageway is pressurised without adversely affecting the surge line position.

Figure 14 illustrates the performance that can be achieved with the arrangement of Figure 13. Lines 38 and 39 respectively indicate the surge line and choke flow conditions achieved with a conventional arrangement as shown

in Figure 1. Lines 40 and 41a represent performance with a structure as shown in Figure 13 without the passageway 13 being pressurised. Applying a pressure of 1.2 bar abs to the passageway displaced the surge line to the position indicated by line 38 and displaced the choke line to the position indicated by line 41b. Application of a still higher pressure of 1.4 bar abs did move the surge line at mid-range speeds but not at higher speeds. Too high a pressure causes a relatively large proportion of the flow to come from the pressurising source, resulting in increased parasitic losses, in addition to demanding a high power pressurising source. As is apparent from Figure 7, the slot should be near to the upstream edge of the wheel to minimise the pressure required for a given flow through the slot. It is believed that the combination of a stepped wheel as in Figure 13 and pressurisation of the passageway 13 should enable the use of a larger than normal profile downstream of the step, thereby increasing the maximum flow for a given size of wheel.

The arrangement of Figure 13 makes it possible to achieve desirable displacements of both the surge and choke flow positions. In some circumstances it is desirable only to displace the choke flow, and an arrangement which can achieve this is shown in Figure 15 which shows a passageway 13 defined between an inlet sleeve 42 and a tubular housing 43. The passageway 13 communicates with an annular cavity 44 via openings 45 in the housing 43. The compressor wheel (not shown) is positioned with the upstream edges of its blades adjacent the upstream edge 46 of openings 47 positioned adjacent the wheel. Air from the

passageway 13 is directed towards the wheel through these openings in a directions with a substantial axial component. In use, in high flow conditions pressure is applied to the cavity 44 to increase the flow through the compressor and hence displace the choke flow to the right in the manner indicated by lines 39 and 41 of Figure 14. This arrangement also has the advantage of increasing the pressure ratio at a given speed and flow compared with standard arrangements.

With axially directed slots as shown in Figures 13 and 15, pressure may be applied only at flows greater than the normal surge flow. The application of pressure over a wide range of flow values may provide benefits however. For example, even at the maximum efficiency point gas will flow into the wheel if the pressure is high enough.

In the embodiments of Figures 13 and 15, it has been found that it is important to arrange the openings such that air is directed with a substantial axial component. This has revealed however a useful effect which can be achieved by directing air in a direction with a substantial radial component in low flow conditions. Figure 16 shows a further embodiment of the invention which takes advantage of this effect.

The arrangement of Figure 16 is similar to that of Figure 1 except that the inlet wall 9 is extended. In low flow conditions the passageway 13 is connected to a source of pressurised air (not shown) rather than communicating with the inlet. In low flow conditions the passageway 13 is pressurised, and as a result an air

flow indicated by line 48 is established. This has the effect of blocking air flow to radially outer portions of the upstream edges 5 of the blades, compressing the air flow as indicated by lines 49. Thus the inlet diameter of the compressor can be effectively reduced and as a result the surge line can be displaced as desired. The extent of the displacement can be controlled by controlling the pressure within the passageway 13. A side effect of pressurising the passageway 13 is that the noise which can result from reverse flow through the slots is suppressed. Thus in a given application a larger inlet diameter may be used than would otherwise be the case, resulting in an increase in choke flow as compared with a standard size inlet.

Figure 17 represents the displacement of the surge line which can be achieved with the arrangement of Figure 16. Line 50 represents the surge line if the passageway 13 is not pressurised, and line 51 represents the surge line when the passageway 13 is pressurised.

Thus the invention enables desirable displacement of the surge line in low flow conditions either by drawing air from the compressor through slots directed at a wide range of angles relative to the wheel axis, or by delivering air to the compressor through slots directed with a substantial radial component relative to the wheel axis. The invention also enables a desirable displacement of the choke flow position in high flow conditions by delivering air to the compressor through slots directed with a substantial axial component relative to the wheel axis.

Although in the description reference is made to "slots", it will be appreciated that the passageway opening in the surface 8 swept by the impeller blades could be in the form of a series of spaced-apart openings.

CLAIMS

1. **A compressor comprising a stationary housing defining an inlet and an outlet, and an impeller wheel mounted for rotation within a chamber defined by the housing between the inlet and outlet, the wheel including a plurality of blades each of which sweeps across an inner surface of the housing chamber, and the housing defining at least one passageway communicating with at least one opening located in the surface of the housing chamber adjacent the wheel, wherein pressure control means are provided to control the pressure within the passageway.**
2. **A compressor according to claim 1, wherein the pressure within the passageway is controlled as a function of the flow rate through the compressor.**
3. **A compressor according to claim 2, wherein the pressure control means maintains a pressure within the passageway less than that within the inlet at least when the flow rate is low relative to a predetermined flow rate.**

4. A compressor according to claim 3, wherein the passageway extends between the opening adjacent the wheel and a further opening located in the throat of a venturi within the inlet.
5. A compressor according to claim 4, comprising means for blocking the passageway when the flow rate is high relative to a predetermined flow rate.
6. A compressor according to claim 4 or 5, comprising a bypass passageway extending between opposite sides of the venturi, and means for obstructing the by pass passageway when the flow rate is low relative to a predetermined flow rate.
7. A compressor according to any preceding claim, wherein the passageway adjacent the opening is arranged such that gas issuing from the opening is directed in a direction with a substantial axial component relative to the axis of rotation of the wheel, and the pressure control means maintains a pressure within the passageway which is higher than that within the inlet at least when the flow rate is high relative to a predetermined threshold.
8. A compressor according to claim 7, wherein the inlet is defined by a tubular cone received within a tubular support, the passageway being

defined between the cone and the housing, the opening being defined between one end of the cone and the housing, and the passageway communicating with the pressure control means through at least one opening in the tubular support.

9. A compressor according to any preceding claim, wherein each blade comprises an upstream edge adjacent the inlet, a first radially outer edge which is in close proximity to and sweeps across the inner surface of the housing, a second radially outer edge which is in close proximity to and sweeps across a surface defined by the inlet, and an intermediate edge extending between the first and second radially outer edges, the opening facing the intermediate edges of the vanes.
10. A compressor according to claim 1, wherein the passageway adjacent the opening is arranged such that gas issuing from the opening is directed in a direction with a substantial radial component relative to the axis of rotation of the wheel, and the pressure control means maintains a pressure within the passageway which is higher than that within the inlet only when the flow rate is low relative to a predetermined threshold.
11. A compressor substantially as herein before described with reference to Figure 9, 10, 11, 12, 13, 15 or 16 of the accompanying drawings.



Application No: GB 9621338.4
Claims searched: 1-10

Examiner: Peter Squire
Date of search: 30 March 1998

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK CI (Ed.P): F1C CFFB CFFC CFFD CFFH CFS

Int CI (Ed.6): F04D 27/00, 02 29/40, 42, 44, 46, 66, 68

Other: Online: EDOC, WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	EP 0526965 A2 (Ishikawajima-Harima) see whole document	1-3, 9, 10
X	WO 92/03660 A1 (Kühnle, Kopp & Kausch) see Figures	1-3, 9, 10
X	US 4990053 (Rohne) see whole document	1, 2, 9, 10
X	US 4930979 (Fisher et al) see Fig.4	1-3, 9, 10
X	US 4930978 (Fisher et al) see Figs.1, 2, and 7	1-3, 9, 10

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

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